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AN ANALYSIS OF SOME FACTORS AFFECTING THE ABUNDANCE OF BLUE MARLIN IN HAWAIIAN WATERS

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SUMMARY

A statistical model was constructed to study the effects of various factors on the abundance of blue marlin, Makaira nigricans, around the main Hawaiian Islands in the third quarter of the year. The model was based on historical records of Japanese longline effort and catch-per-unit-effort (CPUE), and a set of simple assumptions on blue marlin population dynamics.

Third quarter blue marlin CPUE in local waters was shown to be very highly correlated with blue marlin CPUE at the beginning of the year on the mid-Pacific blue marlin grounds south and southwest of Hawaii. The effects of other factors on local blue marlin abundance, such as foreign longlining effort during the first two quarters in local, adjacent, and mid-Pacific waters could not be estimated reliably.

The study confirmed that local abundance of blue marlin is dictated largely by events occurring outside the Fishery Conservation Zone (FCZ). Although benefits to domestic blue marlin fishers could be expected under certain conditions, the quantitative effects of excluding foreign longline vessels from the FCZ cannot be computed.

BACKGROUND AND PURPOSE

The development of measures to control the foreign catch of billfishes in the Fishery Conservation Zone (FCZ) is based primarily on the idea that foreign fishing vessels compete significantly with domestic vessels on the local grounds, or, in the outer reaches of the FCZ, intercept fish migrating to local grounds from more distant waters. To the extent that this concept is valid, domestic harvesters could benefit from the exclusion of foreign vessels from particular areas of the FCZ during the seasons when billfish are most abundant.

If billfish occurring locally were all homegrown fish, then excluding foreign vessels would unquestionably help local fishermen. But if the billfish taken in local waters originate elsewhere, or are part of wide-ranging populations, the expulsion of foreign longliners would not necessarily lead to higher local catch rates. If the displaced foreign vessels were redeployed in other regions of the billfish's range, they would still affect local catch rates by reducing the number of billfish migrating from those regions to local waters. The net impact of removing the competitors would depend on the relative concentrations of billfish in the various areas and their vulnerability to the foreign longline gear. Unfortunately, with our meager understanding of billfish biology and the effects of fishing, we have been unable to predict the results of exclusionary policies with much confidence. Previous studies, such as that by Lovejoy, have stressed that at best only general qualitative conclusions could be reached, and that even these were based more on assumptions than established facts.

This report summarizes our recent attempts to examine some of the ideas expressed above, with respect to blue marlin, Makaira nigricans, only. Our approach was to assemble the best fishery statistics available, construct a simple but logical conceptual model of local blue marlin abundance, and see what conclusions could be drawn. In particular, we considered the relationships between the abundance of blue marlin in Hawaiian waters during the third quarter of the year and several factors thought to affect it. These included the abundance of blue marlin in the mid-Pacific at the beginning of the year, recruitment to the stock during the first half of the year, and the amount of fishing effort applied to the stock in this same period.

TRENDS IN ANNUAL ABUNDANCE AND FISHING EFFORT

We assumed a single population of blue marlin occupying the central Pacific, whose geographical distribution changes seasonally. While blue marlin may be found in Hawaiian waters throughout the year, their abundance seems to reach a peak in the summer months. Presumably they migrate into local waters from the equatorial waters to the south and southwest.

If this is so, it should be reflected in the historical records of blue marlin abundance around the main Hawaiian Islands and in more distant waters. The only available sources of such information are the blue marlin catch-per-unit-effort (CPUE) statistics of domestic longliners, fishing around Hawaii, and the CPUE of Japanese tuna longline vessels operating throughout the range of the blue marlin stock. In the area of our concern, the vessels target on yellowfin tuna, Thunnus albacares, and bigeye tuna, T. obesus, and catch blue marlin and other species incidentally. If systematic changes in tuna targetting have occurred over the years, the CPUE trends for blue marlin may not reflect actual changes in abundance. Having no recourse, we assume no changes in blue marlin catchability have occurred.

For purposes of this analysis, we defined three zones in the central Pacific assumed to encompass most of the blue marlin, and computed the historical trends of CPUE in each. The areas are:

Local - The two 5° squares surrounding the main Hawaiian Islands, from long. 155° to 160°W and lat. 15° to 25°N.

Adjacent - The seven 5° squares bordering on the local area to the east, south, and west.

Mid-Pacific - All remaining 5° squares in the region from long. 150°W to 150°E and lat. 10°S to 25°N.

The areas are depicted in Figure 1. The 5° square unit was used because this is the smallest area by which Japanese longline statistics are available. The 'local' area is equivalent to the FCZ, for all practical purposes, and roughly coincides with the area where the domestic longliners fish.

Within each area we compiled the historical records of blue marlin, yellowfin tuna, and bigeye tuna CPUE, averaged over the whole year, between 1956 and 1980. A complete record was available only for Japanese longlining. Domestic data were available only for 1959 to 1978.

Nominal fishing effort by the two gears was also computed for each area. The CPUE and effort statistics are listed in Tables 1 and 2. Note that the units are different for the two gear types. Domestic CPUE is in metric tons/trip, and effort is measured in number of vessel trips.

Japanese CPUE is in number of blue marlin caught/1,000 hooks fished and effort is in thousands of hooks fished. In the case of the mid-Pacific area, Japanese effort since 1966 was expanded to include estimated effort by other high-seas longliners (primarily Korean).

The trends in annual CPUE and effort data are also depicted, for blue marlin only, in Figures 2-5. The actual values are not shown. Instead, we have plotted the magnitude of each year's CPUE and effort relative to the 1978 figures.

The most interesting features of the annual plots are

1 - While mid-Pacific foreign effort has fluctuated, the most dramatic changes in longline effort have been in adjacent and local waters. Domestic longlining has gone steadily downhill, in terms of both CPUE and effort since 1959. Japanese longlining in local and adjacent waters mushroomed during the 1960', but has since tended to stabilize or decline.

2 - Blue marlin CPUE has tended to decline in all areas. (However, in the early 1970's, the domestic blue marlin CPUE is biased downward because of underreporting.)

In terms of explaining changes in local blue marlin abundance, the annual plots make two points. First, our assumption of a common blue marlin stock supporting fisheries in the three areas is reasonable, since local CPUE statistics follow the same basic trends as those in the mid-Pacific. Second, barring collosal leaps in relative fishing power, rapidly declining nominal effort by any gear would enhance survival of blue marlin and probably increase CPUE. Therefore it appears that year-to-year changes in abundance of blue marlin, even locally, are not affected by domestic longlining. (Within-year impacts would be expected.)

QUARTERLY PATTERNS

Other information emerges when the CPUE and effort statistics are compiled by quarters. These detailed data are given in Table 3, for blue marlin only. To simplify analysis further, we averaged the quarterly data over all years, and plotted the resulting CPUE and effort statistics in Figures 6-9. Again, relative values are plotted, with the third quarter (July-September) taken as the base period.

All the quarterly plots suggest an increase in apparent abundance (or availability) of blue marlin in the third quarter, but especially those for adjacent and local areas. This supports the assumption that during the first half of the year blue marlin migrate into local waters from a major distribution center south and southwest of the main islands.

MODEL OF LOCAL BLUE MARLIN ABUNDANCE

On the basis of trends and patterns revealed in the annual and quarterly statistics, we constructed a simple model of local blue marlin abundance in the third quarter.

Logically, the model can be separated into three pieces. The first states that the local blue marlin abundance in the third quarter is equal to the mid-Pacific abundance during the third quarter times the proportion available in the local area in this season. This proportion is assumed to be constant or, at most, to vary from year to year in a random fashion. The second part states that the third-quarter abundance in the mid-Pacific is equal to the mid-Pacific abundance at the beginning of the year times the proportion of those blue marlin surviving to the third quarter, plus all new blue marlin recruiting to the population during the first half of the year and still alive during the third quarter. The third piece of the model states that the survival rate during the first two quarters is a function of natural mortality factors (assumed constant) and fishing mortality on the stock (assumed proportional to foreign longlining effort in the local, adjacent, and mid-Pacific areas).

Mathematically inclined readers will find the model equation in the Appendix.

Of the factors in the model, the only ones known explicitly are the nominal fishing efforts. However, we made the usual assumption that CPUE is proportional to fish abundance, on the average, and substituted Japanese longline blue marlin CPUE statistics into the model. The third quarter local abundance in a given year was assumed to be proportional to the average of the Japanese CPUE's during the second, third, and fourth quarters in the local area. (The resulting statistic is called CPUEL.) The mid-Pacific abundance at the beginning of the year was assumed proportional to the average of the mid-Pacific Japanese CPUE's in the third and fourth quarters of the previous year and the first and second quarters of the current year. (The resulting statistic is denoted CPUEM.) Since third-quarter Japanese effort in local waters did not begin until 1962, we fit the model to data for 18 years, 1962-79 (1980 Japanese data have not yet been compiled on a quarterly basis). The data are listed in Table 4.

FITTING THE MODEL TO DATA

In fitting the model, the CPUE data were first converted to logarithms to satisfy mathematical requirements. For CPUEL and CPUEM, the converted values are denoted LOG(CPUEL) and LOG(CPUEM).

Figures 10 and 11 show that the transformed third quarter local abundance [LOG(CPUEL)] is directly related to the transformed mid-Pacific abundance at the beginning of the year [LOG(CPUEM)]. Of course, this was expected from the high correlation of local and mid-Pacific CPUE's in the annual data.

If LOG(CPUEM) is considered by itself as a predictor of LOG(CPUEL), we find that it can explain 80% of the year-to-year variation in LOG(CPUEL). The observed LOG(CPUEL) and the values predicted by information on LOG(CPUEM) alone are shown in Figure 12. Results in the original units are in Figure 13. In most years, the observed and predicted values are not far apart. However, the model tends to underestimate the observed values in the earlier years, and to overestimate them in more recent years. This would be expected to happen if the survival rate during the first two quarters, or the recruitment that occurs during this period, declined over the 18-year period.

In a second fitting stage, we therefore added the recruitment and survival components. We assumed that recruitment could either increase linearly, decrease linearly, or remain constant during the period. In the survival function, we assumed fishing mortality during the first two quarters was a linear combination of accumulated foreign longlining effort in the mid-Pacific, adjacent, and local waters.

When this more complete model was fit to the data, we found that it explained 95% of the annual variation in LOG(CPUEL). The fitted model and the corresponding observed values are displayed in Figure 14. In the original units, results are shown in Figure 15.

Not surprisingly, recruitment was estimated to have declined over the years, and foreign effort was predicted as having a negative impact on blue marlin abundance in all three areas. These results are consistent with the significant negative correlations between foreign effort and blue marlin CPUE apparent in the annual summary plots, and the marked decline in blue marlin CPUE in all areas.

This statistical model may seem to be a successful explanatory device. However, this conclusion must be tempered, because the precision of the estimates of various effects is extremely low (see Appendix). Statistically, we could not reject the claim, for example, that foreign longlining has had no effect on blue marlin survival in the first two quarters.

Nor would the model be very satisfactory as a predictor. In the first place, the model is oversimplified. Secondly, as just noted, the parameters of the fitted model are poorly estimated. This is due in part to the dearth of data; only 18 years of data were available for estimating 6 unknown parameters. It is also due to linear dependencies between several of the independent variables. This means that while it may be logical to add the effort and recruitment components, it is not possible to statistically differentiate between their effects.

CONCLUSIONS

Despite the cautionary remarks, this modeling exercise has been beneficial. First, it has shown convincingly, if not conclusively, that the fate of local blue marlin fishing is dictated by events outside the FCZ. Year-to-year changes in local blue marlin catch rates tend to reflect similar changes in the mid-Pacific.

Second, the consistency among the various CPUE statistics suggests that they may be fairly good indicators of blue marlin abundance.

Third, the exercise has highlighted the inadequacy of our scientific understanding of blue marlin and our inability to clearly explain, much less forecast, changes in local abundance. This in spite of the fact that we used the best data available.

Although our analysis was different in character from the well-known Lovejoy simulation study, it shared some of the assumptions of that analysis, and substantiated others. It also had common objectives. As Lovejoy did with a compartmental migration model, we hoped to study the effects of excluding foreign longline effort from local waters. In our simple statistical model, no explicit assumptions were made about migration. However, if the effects of foreign fishing effort in the various areas had been estimated with enough precision, we could have made rough predictions of the net effects of excluding foreign vessels from the local area, under various assumptions about their redistribution in the other two areas (or outside all three areas). Our belief is that quantitative predictions are not yet possible. As Lovejoy concluded, the most that can be said is that some benefit will accrue, provided catchability of blue marlin by foreign longliners is constant. Needless to say, a meaningful comparative study of alternative exclusionary policies in the FCZ would be out of the question.

APPENDIX

Let CPUEL = Japanese longline CPUE in local waters at middle of third quarter (average of second, third, and fourth quarter statistics).

CPUEM = Japanese longline CPUE in mid-Pacific waters at beginning of year (average of third and fourth quarter statistics of previous year and first and second quarter statistics of current year).

HL = Half of foreign longline effort in local waters during second quarter, plus half of third quarter effort.

HA = Total foreign longline effort in adjacent waters during first two quarters, plus half of third quarter effort.

HM = Total foreign longline effort in mid-Pacific waters during first two quarters, plus half of third quarter effort.

The complete nonlinear regression model is:

$$\ln(\mathrm{CPUEL}) = A + \ln\{\mathrm{CPUEM} + C + D\,(\mathrm{year} - 1962)\} - B_1 \cdot \mathrm{HM} - B_2 \cdot \mathrm{HA} - B_3 \cdot \mathrm{HL} + \varepsilon$$

where the additional symbols are

C = Constant proportional to intercept of linear recruitment function

D = Constant proportional to slope of linear recruitment function

B_1 = Mid-Pacific area catchability coefficient

B_2 = Adjacent area catchability coefficient

B_3 = Local area catchability coefficient

Table 2.--Annual statistics of CPUE and nominal effort for Japanese longliners in adjacent and mid-Pacific areas. BM = blue marlin, YF = yellowfin tuna, BE = bigeye tuna.

	Adjacent area				Mid-Pacific area			
		CPUE				CPUE		
Year	Effort	BM	YF	BE	Effort	BM	YF	BE
1956	227	0.666	0.683	16.676	26,785	2.768	16.315	10.592
1957	120	0.740	1.256	21.373	45,971	3.088	21.175	10.280
1958	505	1.113	1.273	25.308	48,124	2.906	20.090	14.291
1959	1,237	0.512	2.751	21.006	50,975	2.182	18.221	10.731
1960	1,581	1.278	3.755	18.356	52,038	1.989	22.751	8.532
1961	2,462	2.054	3.082	23.938	68,854	2.263	17.453	9.078
1962	5,596	1.702	1.413	26.652	71,412	2.121	14.951	6.086
1963	5,864	1.748	0.914	17.551	84,088	1.606	15.158	7.939
1964	7,561	0.929	1.639	12.221	66,815	1.554	15.935	7.639
1965	1,767	1.143	2.498	8.557	66,208	1.229	12.375	7.087
1966	2,283	0.993	1.429	13.516	68,098	1.260	18.370	6.332
1967	3,204	0.980	1.178	13.558	57,390	1.359	10.370	6.425
1968	3,970	0.698	1.507	8.272	54,260	1.091	13.107	5.325
1969	2,311	0.789	2.076	9.459	57,086	1.291	13.580	7.014
1970	7,365	1.227	3.917	8.742	61,140	1.593	12.758	5.562
1971	3,888	0.576	2.077	8.532	61,793	0.865	10.448	6.270
1972	5,088	0.854	1.407	9.615	79,229	1.025	10.322	7.694
1973	6,133	0.492	1.207	9.229	57,991	0.899	10.510	6.140
1974	3,462	0.568	1.462	7.340	65,601	0.809	5.313	6.807
1975	4,023	0.296	1.247	8.325	57,027	0.479	5.825	7.396
1976	5,305	0.459	1.123	8.752	55,448	0.719	9.050	7.186
1977	3,438	0.290	1.076	9.481	59,343	0.768	14.535	8.003
1978	7,392	0.538	0.867	10.240	54,276	0.828	17.287	6.720
1979	4,743	0.406	2.043	7.697	75,488	0.644	12.464	7.200
1980	4,977	0.535	1.265	9.862	93,390	0.752	14.132	5.828

Units: Japanese Effort = 1,000's of hooks
CPUE = Number of fish per 1,000 hooks

Table 3.--Quarterly statistics of blue marlin CPUE and nominal effort by domestic and Japanese longliners.

		Domestic local		Japanese local		Japanese adjacent		Japanese mid-Pacific	
Year	Quarter	Effort	CPUE	Effort	CPUE	Effort	CPUE	Effort	CPUE
1961	1	222	0.045	30	1.058	1,137	1.203	20,925	1.844
	2	228	0.110	21	1.228	1,244	2.629	18,599	2.326
	3	218	0.217	0	--	68	5.718	16,065	2.547
	4	245	0.107	0	--	10	2.043	13,263	2.492
1962	1	138	0.057	8	0.236	1,801	1.282	22,035	1.905
	2	207	0.110	361	1.416	3,445	1.783	16,079	2.190
	3	200	0.135	12	2.790	262	3.629	17,574	2.219
	4	216	0.067	16	0.544	86	1.369	15,723	2.243
1963	1	185	0.052	167	0.388	1,909	0.893	23,968	1.510
	2	194	0.113	242	1.767	3,629	2.156	22,461	1.663
	3	187	0.146	40	1.660	259	2.514	18,441	1.683
	4	204	0.082	19	0.560	65	0.981	19,215	1.584
1964	1	171	0.023	652	0.445	2,003	0.767	23,594	1.493
	2	183	0.056	779	0.740	4,739	1.047	17,179	1.782
	3	165	0.161	106	1.515	110	1.834	14,773	1.436
	4	211	0.091	75	0.464	706	0.454	11,267	1.488
1965	1	156	0.044	84	0.470	300	0.502	23,329	1.161
	2	159	0.124	462	0.828	743	1.361	21,535	1.223
	3	141	0.134	43	1.287	504	1.245	12,452	1.329
	4	173	0.066	50	0.707	219	1.039	8,890	1.279
1966	1	126	0.053	11	0.421	355	0.211	16,669	1.061
	2	152	0.093	439	0.985	1,533	1.104	20,684	1.231
	3	145	0.124	7	0.502	292	1.437	18,124	1.385
	4	191	0.068	6	2.462	101	0.756	12,620	1.399
1967	1	153	0.021	48	0.573	1,054	0.579	19,586	1.050
	2	141	0.080	911	0.763	1,818	1.096	18,020	1.554
	3	133	0.112	55	0.939	197	2.313	12,505	1.666
	4	193	0.056	17	2.101	134	0.581	7,277	1.161
1968	1	126	0.020	135	0.443	667	0.673	15,146	0.850
	2	121	0.071	915	0.691	2,750	0.741	17,692	1.357
	3	112	0.119	3	0.269	57	1.348	14,040	1.261
	4	155	0.045	126	0.426	493	0.415	7,379	0.621

Table 3.--Continued.

		Domestic local		Japanese local		Japanese adjacent		Japanese mid-Pacific	
Year	Quarter	Effort	CPUE	Effort	CPUE	Effort	CPUE	Effort	CPUE
1969	1	119	0.021	428	0.128	596	0.494	18,301	0.992
	2	121	0.052	320	0.871	518	1.003	15,788	1.349
	3	139	0.135	122	1.102	539	1.438	13,349	1.622
	4	165	0.049	373	0.230	656	0.352	9,645	1.305
1970	1	117	0.009	226	0.145	1,456	0.363	20,448	1.329
	2	129	0.049	183	1.593	3,609	1.533	14,847	1.991
	3	148	0.108	250	1.818	976	2.199	16,282	1.861
	4	172	0.073	304	0.633	1,322	0.623	9,562	1.083
1971	1	128	0.038	333	0.171	928	0.257	22,507	0.710
	2	142	0.015	50	0.530	1,420	0.794	16,684	0.822
	3	157	0.001	92	0.972	434	1.331	14,436	1.157
	4	170	0	186	0.322	1,104	0.267	8,164	0.863
1972	1	138	0	171	0.087	925	0.228	26,529	1.124
	2	120	0	160	0.575	2,361	0.768	21,675	1.086
	3	115	0	59	0.817	1,419	1.604	21,271	0.956
	4	128	0	226	0.198	382	0.109	9,751	0.770
1973	1	107	0	245	0.093	2,357	0.335	22,128	0.965
	2	111	0.002	506	0.191	2,881	0.552	12,773	0.969
	3	102	0.020	15	0.461	362	1.386	13,652	0.723
	4	140	0.012	525	0.175	532	0.248	9,437	0.901
1974	1	83	0.004	586	0.228	969	0.428	20,181	0.867
	2	92	0.014	1,106	0.454	1,207	0.726	17,371	0.976
	3	91	0.034	367	0.699	716	0.795	14,451	0.828
	4	119	0.011	557	0.200	568	0.181	13,595	0.484
1975	1	102	0.005	283	0.067	1,256	0.093	24,952	0.357
	2	83	0.008	236	0.152	1,599	0.322	8,137	0.565
	3	77	0.019	54	0.458	1,059	0.512	11,919	0.723
	4	111	0.015	129	0.053	107	0.158	12,017	0.432
1976	1	110	0.006	279	0.046	1,195	0.276	17,057	0.506
	2	97	0.011	1,122	0.178	1,859	0.411	15,035	0.856
	3	131	0.022	57	0.350	1,816	0.703	13,333	0.894
	4	133	0.021	198	0.206	433	0.140	10,022	0.642
1977	1	91	0.006	502	0.113	339	0.067	21,334	0.609
	2	97	0.022	442	0.212	2,178	0.267	12,409	0.794
	3	111	0.041	253	0.575	694	0.514	13,625	0.873
	4	138	0.026	219	0.314	226	0.154	11,973	0.902

Table 3.--Continued.

		Domestic local		Japanese local		Japanese adjacent		Japanese mid-Pacific	
Year	Quarter	Effort	CPUE	Effort	CPUE	Effort	CPUE	Effort	CPUE
1978	1	127	0.023	15	0	620	0.301	18,488	0.765
	2	126	0.044	709	0.383	4,452	0.539	13,744	1.076
	3	112	0.050	804	0.761	1,713	0.749	11,508	0.871
	4	138	0.028	99	0.111	605	0.175	10,534	0.563
1979	1	--	--	86	0.069	1,613	0.241	22,866	0.537
	2	--	--	351	0.273	2,619	0.517	20,069	0.753
	3	--	--	40	0.595	260	0.568	17,897	0.600
	4	--	--	207	0.101	249	0.120	14,653	0.713

Units: Japanese Effort = 1,000's of hooks
CPUE = Number of fish per 1,000 hooks

Domestic Effort = Number of trips
CPUE = Metric tons per trip

Table 4.--Data for fitting abundance models.
(Some data listed here were not used.)

Year	CPUED	CPUEL	CPUEM	HD	HL	HA	HM	HM (raised)
1960	0.259	1.6582	3.7939	200	150	1,525	36,168	36,168
1961	0.217	2.8864	4.8098	223	10	2,417	47,557	47,557
1962	0.135	2.5460	4.5677	204	187	5,378	46,901	46,901
1963	0.146	2.1779	3.8190	190	141	5,669	55,650	55,651
1964	0.161	1.6328	3.2717	174	443	6,799	48,160	48,160
1965	0.134	1.4851	2.6551	150	253	1,296	51,091	51,092
1966	0.124	1.8117	2.4509	149	224	2,035	46,415	48,736
1967	0.113	1.8720	2.6947	137	484	2,971	43,860	49,562
1968	0.119	1.0864	2.5176	116	460	3,447	39,859	42,649
1969	0.136	1.0970	2.1120	130	221	1,385	40,765	43,619
1970	0.108	1.7142	3.1243	138	217	5,554	43,436	49,083
1971	0.001	1.1797	2.2391	150	72	2,565	46,410	60,333
1972	0.000	0.9235	2.1159	118	110	2,997	58,841	76,494
1973	0.021	0.5839	1.8310	106	261	5,420	41,728	54,247
1974	0.034	0.6462	1.7349	92	737	2,535	44,719	53,735
1975	0.019	0.4370	1.1172	80	146	3,386	39,049	48,812
1976	0.022	0.3909	1.2589	114	590	3,963	38,759	50,387
1977	0.041	0.4976	1.4706	104	348	2,864	40,556	52,724
1978	0.050	0.5845	1.8092	119	757	5,930	37,987	49,383
1979	--	0.5182	1.3635	--	195	4,363	51,885	67,450

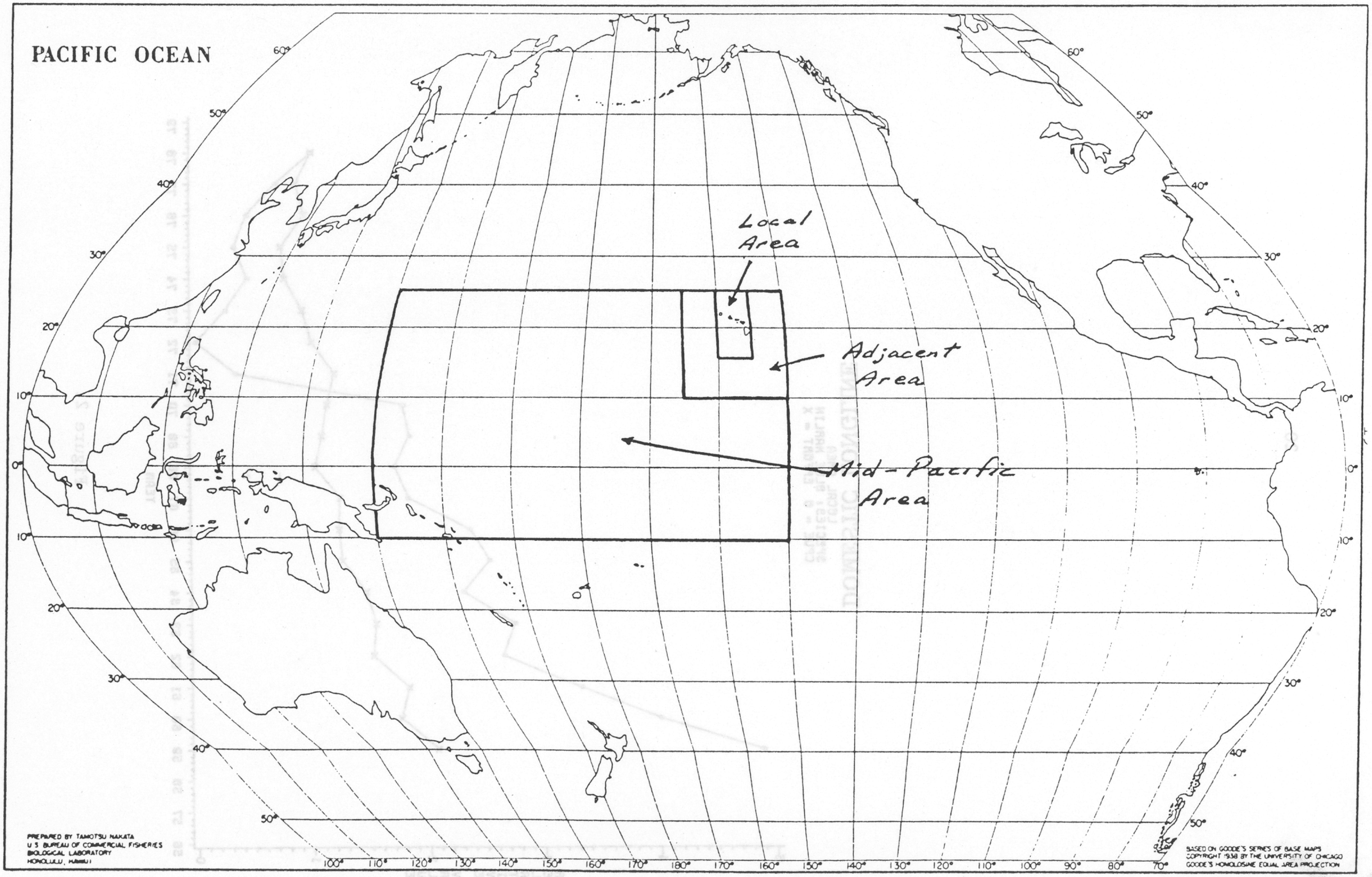

PACIFIC OCEAN
Local Area
Adjacent Area
Mid-Pacific Area
60°
50°
40°
30°
20°
10°
0°
100°
110°
120°
130°
140°
150°
160°
170°
180°
90°
80°
70°
PREPARED BY TAMOTSU NAKATA
U.S. BUREAU OF COMMERCIAL FISHERIES
BIOLOGICAL LABORATORY
HONOLULU, HAWAII
BASED ON GOODE'S SERIES OF BASE MAPS
COPYRIGHT 1938 BY THE UNIVERSITY OF CHICAGO
GOODE'S HOMOLOSINE EQUAL AREA PROJECTION

Figure 1

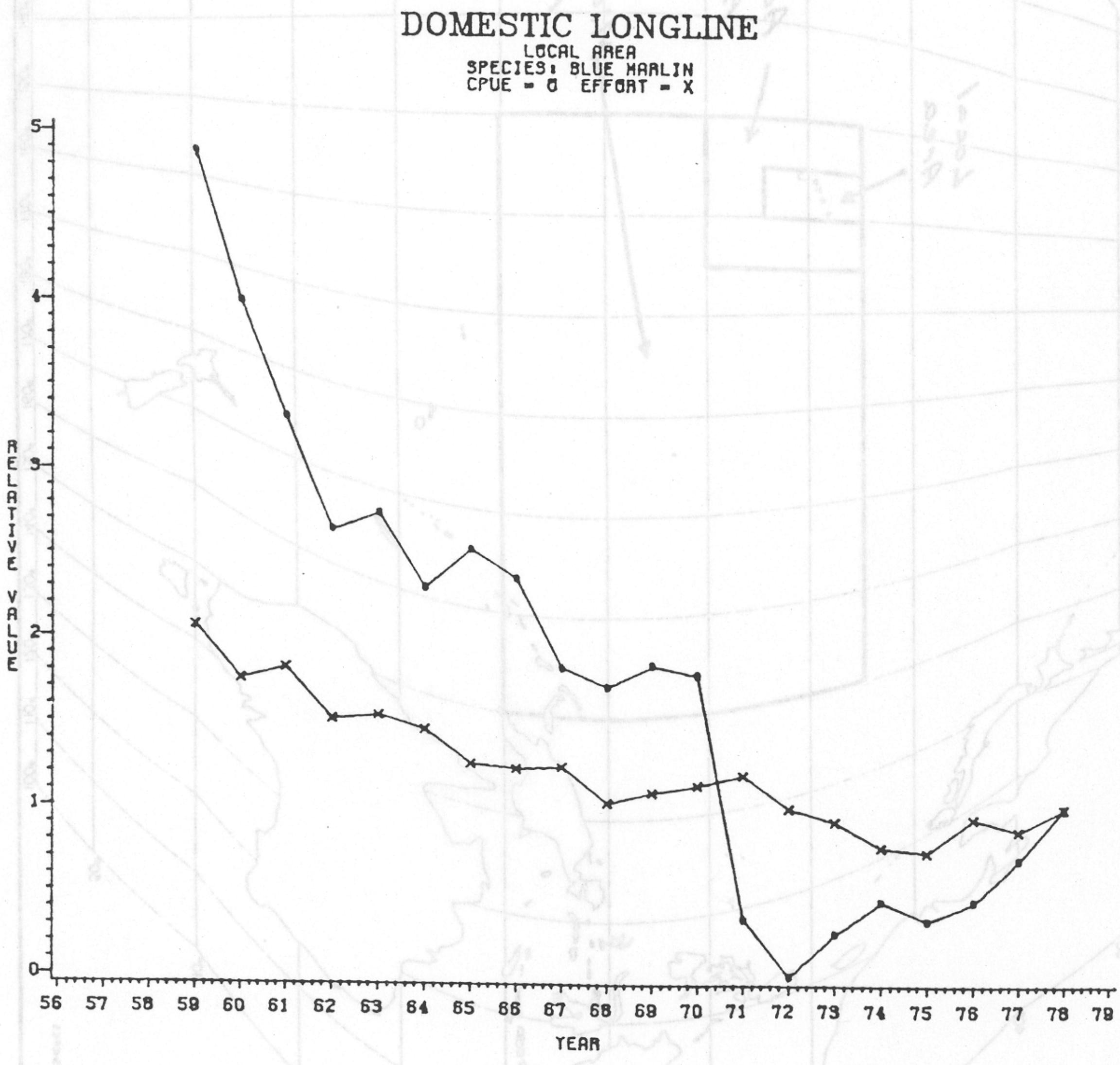

DOMESTIC LONGLINE
LOCAL AREA
SPECIES: BLUE MARLIN
CPUE = O EFFORT = X
RELATIVE VALUE
0
1
2
3
4
5
56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79
YEAR

Figure 2.

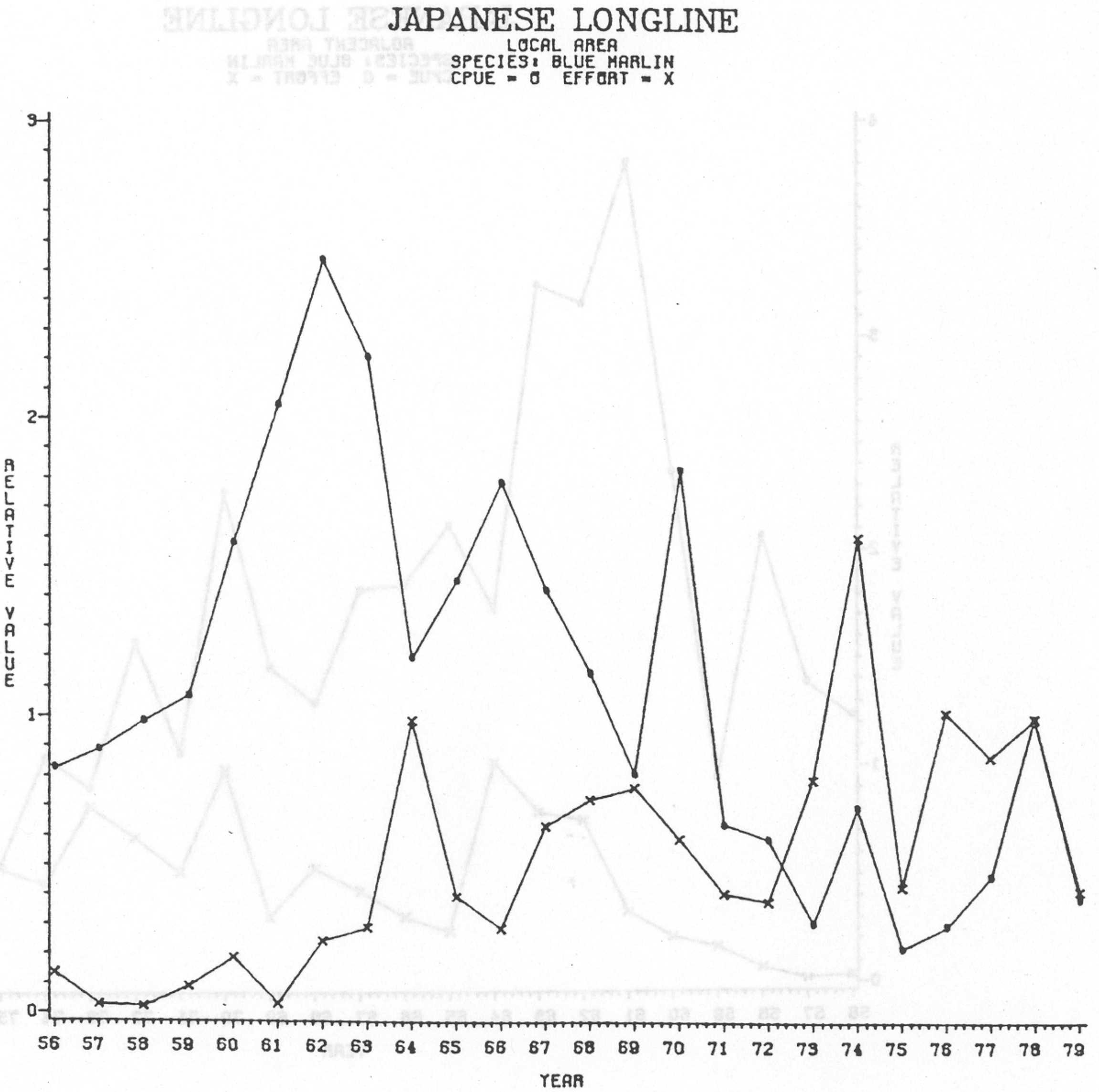

JAPANESE LONGLINE
LOCAL AREA
SPECIES: BLUE MARLIN
CPUE = O EFFORT = X
RELATIVE VALUE
0
1
2
3
56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79
YEAR

Figure 3.

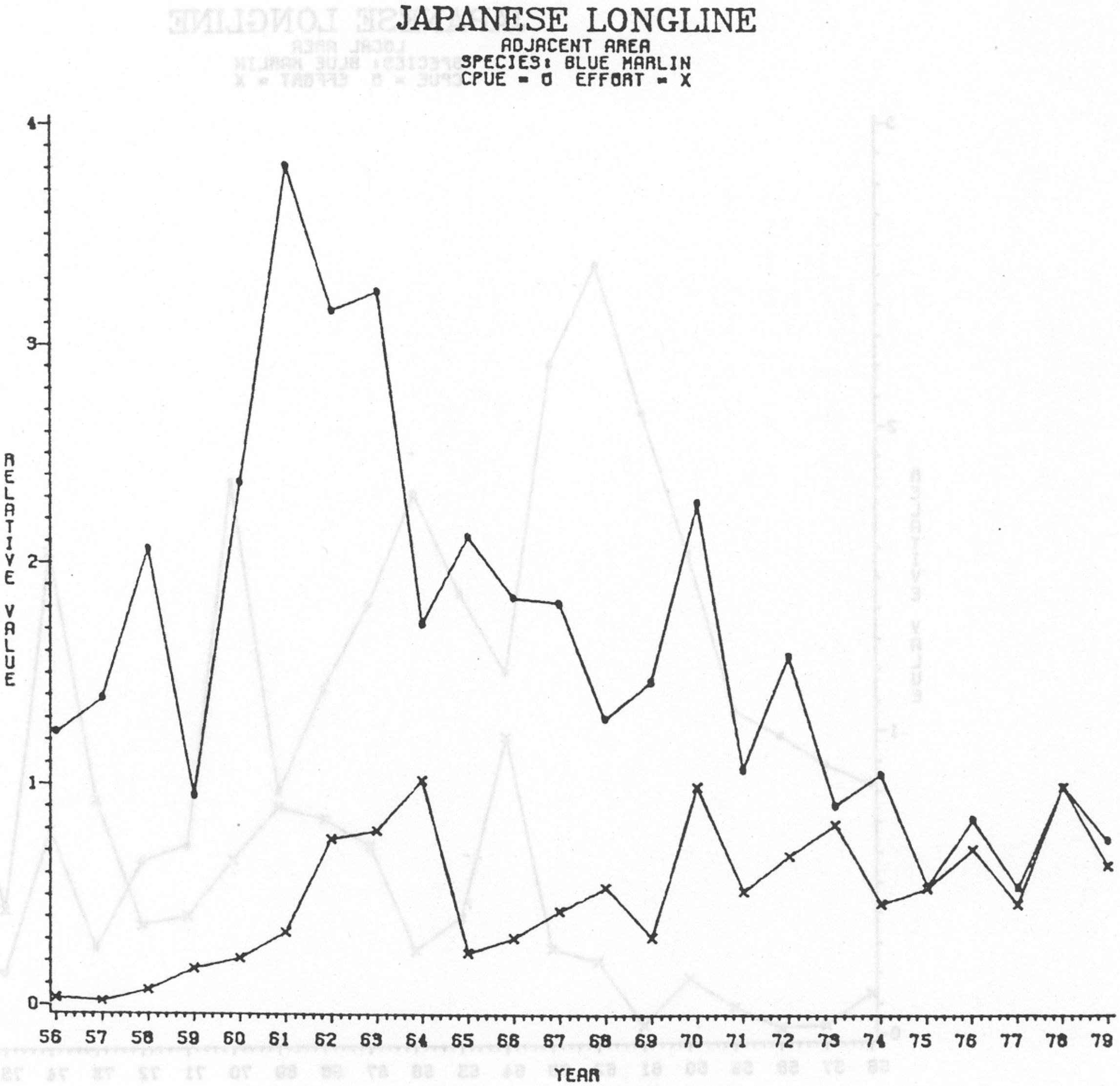

JAPANESE LONGLINE
ADJACENT AREA
SPECIES: BLUE MARLIN
CPUE = O EFFORT = X
RELATIVE VALUE
YEAR
0
1
2
3
4
56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79

Figure 4.

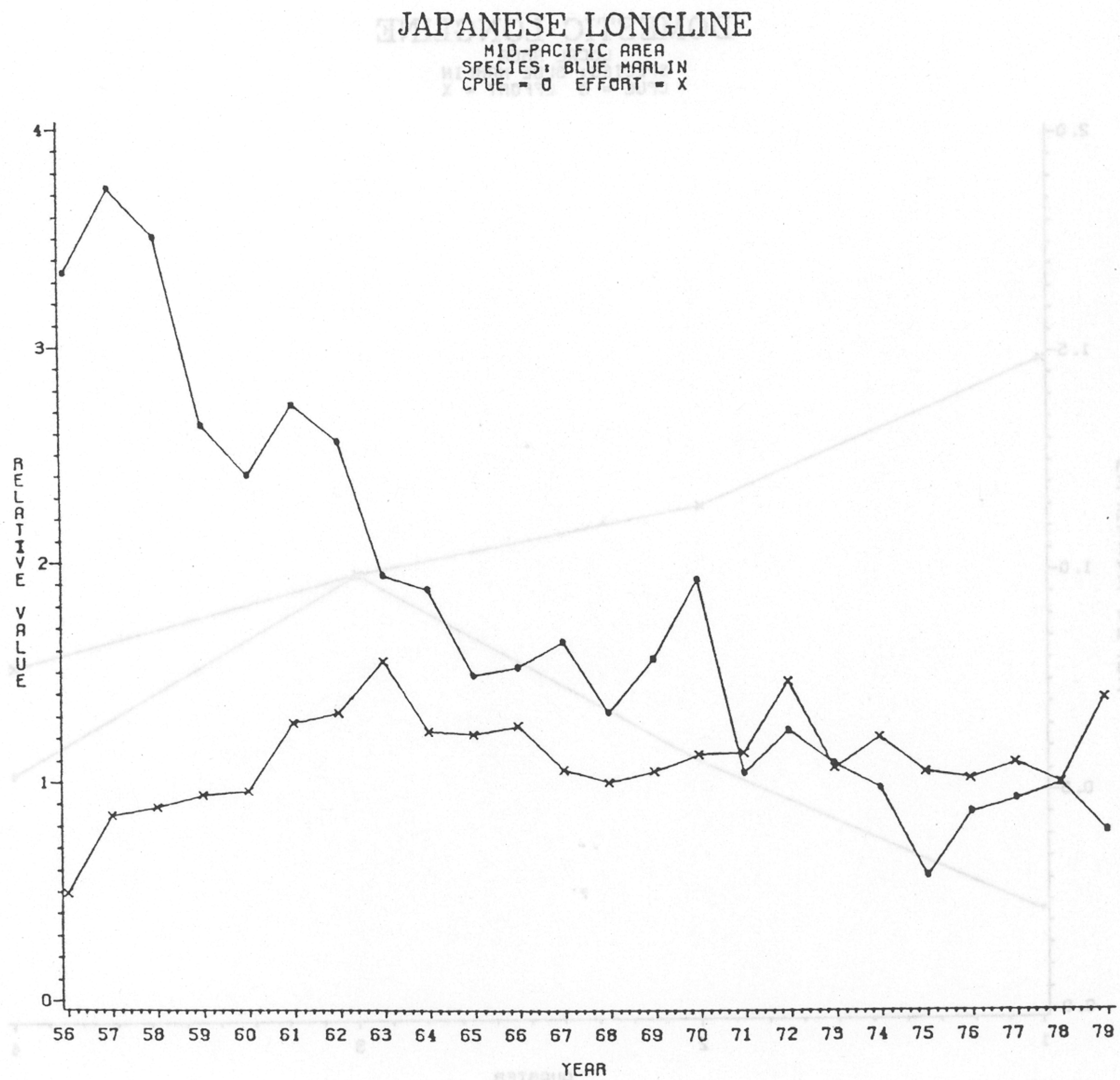
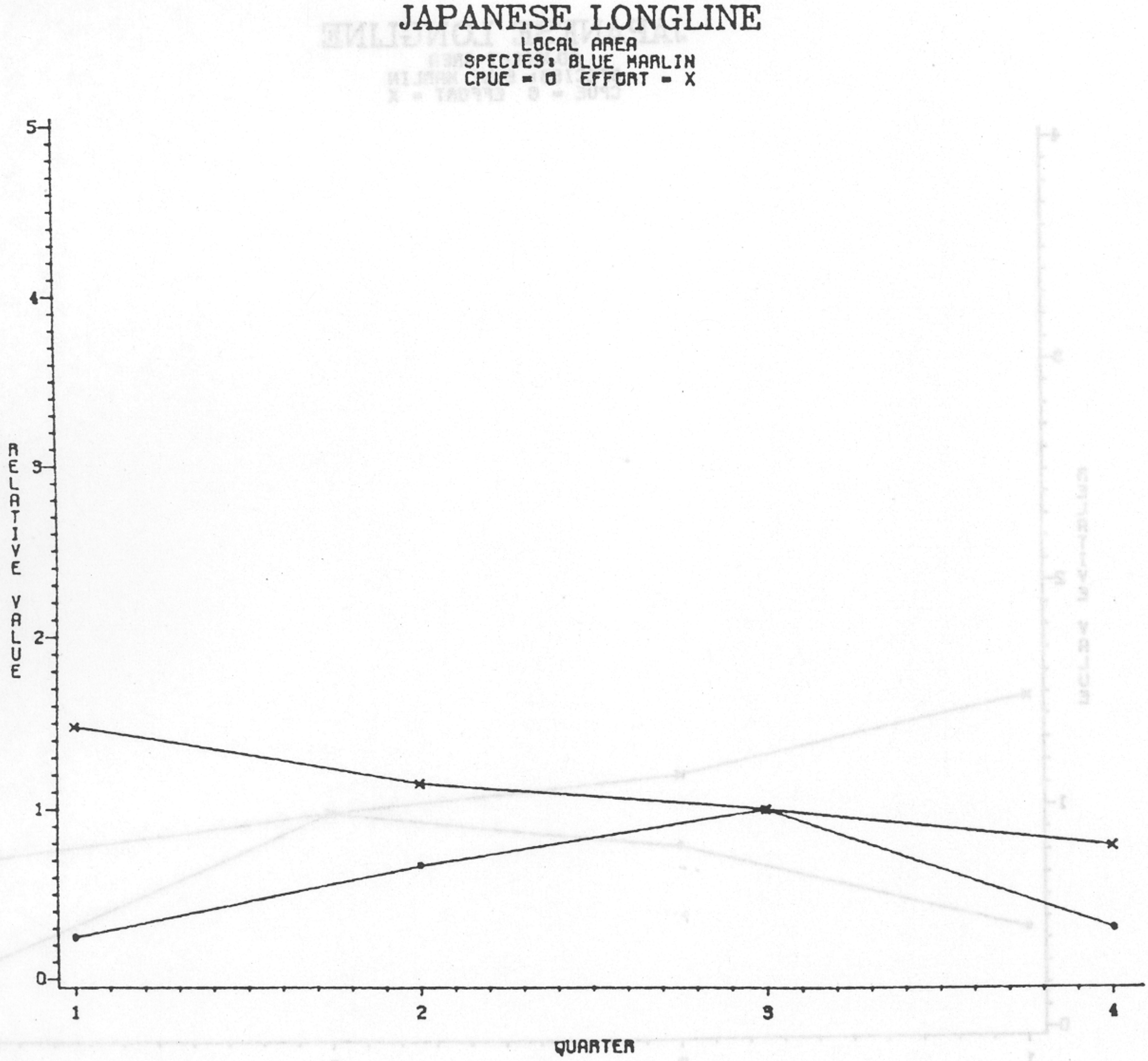

JAPANESE LONGLINE
MID-PACIFIC AREA
SPECIES: BLUE MARLIN
CPUE = O EFFORT = X
RELATIVE VALUE
0
1
2
3
4
56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79
YEAR

Figure 5.



JAPANESE LONGLINE
LOCAL AREA
SPECIES: BLUE MARLIN
CPUE = O EFFORT = X
RELATIVE VALUE
QUARTER
0
1
2
3
4
5
1
2
3
4

Figure 7.

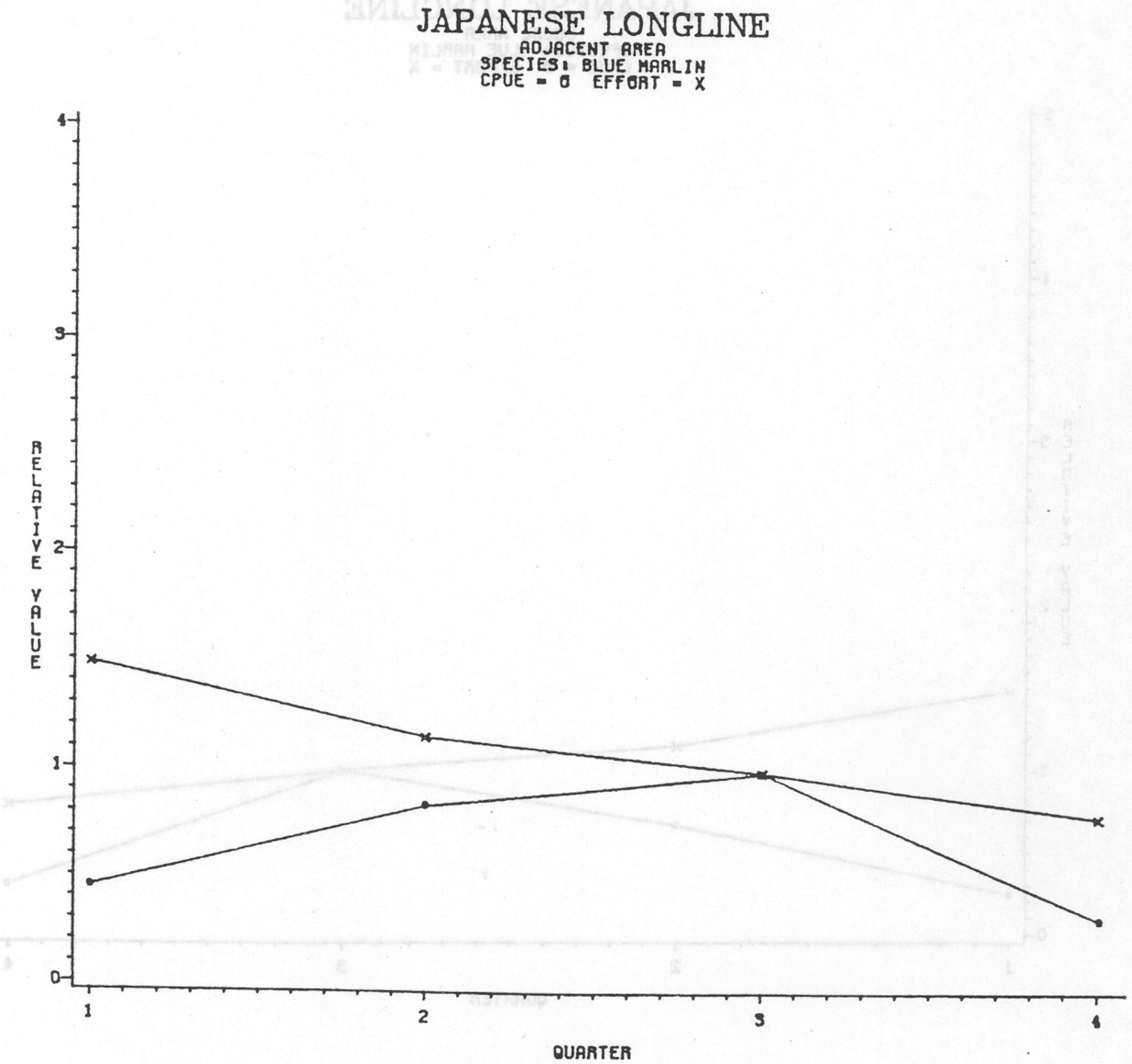
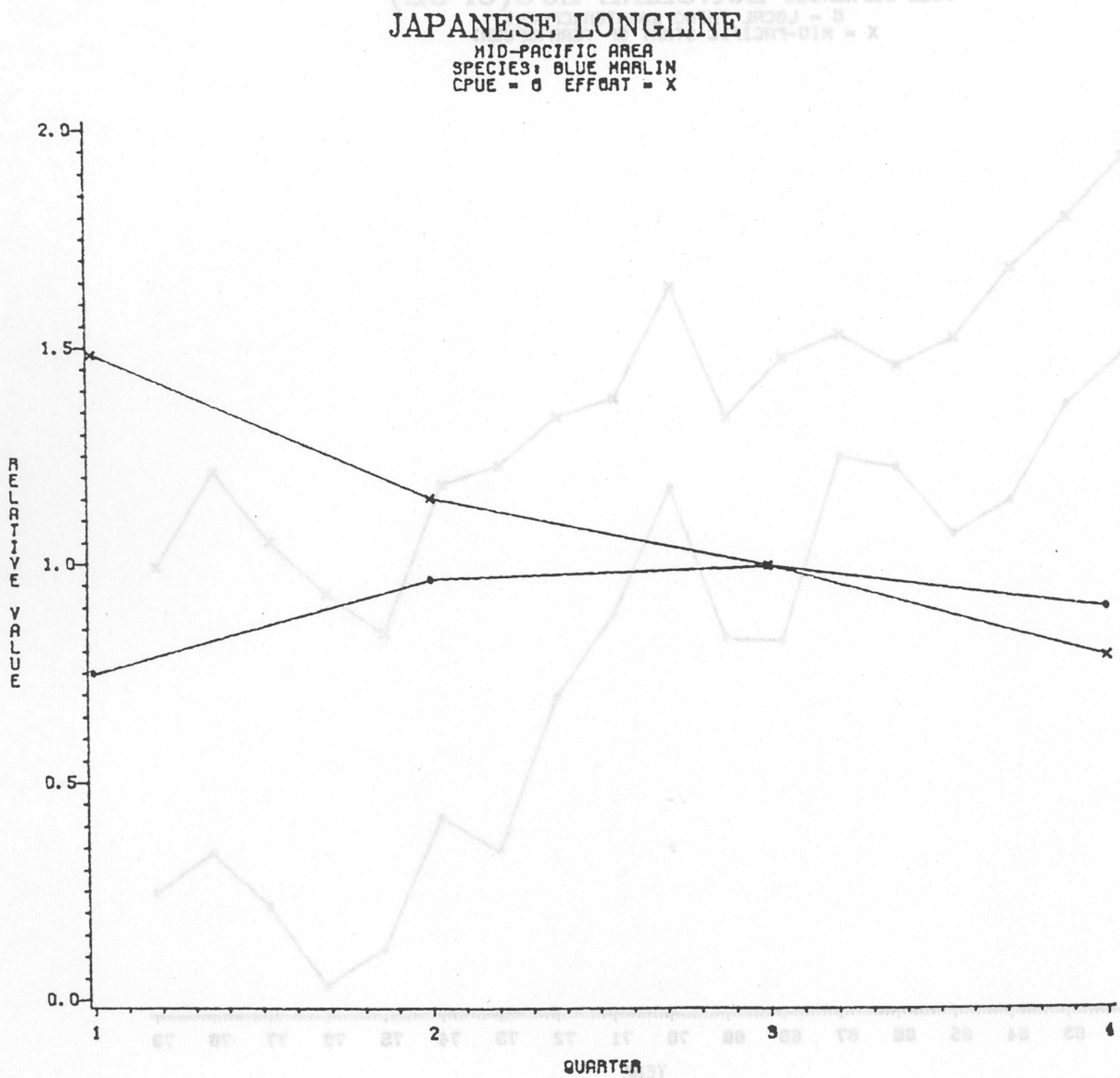

JAPANESE LONGLINE
ADJACENT AREA
SPECIES: BLUE MARLIN
CPUE = O EFFORT = X
RELATIVE VALUE
QUARTER
0
1
2
3
4

Figure 8.



JAPANESE LONGLINE
MID-PACIFIC AREA
SPECIES: BLUE MARLIN
CPUE = O EFFORT = X
RELATIVE VALUE
2.0
1.5
1.0
0.5
0.0
1
2
3
4
QUARTER

Figure 9.

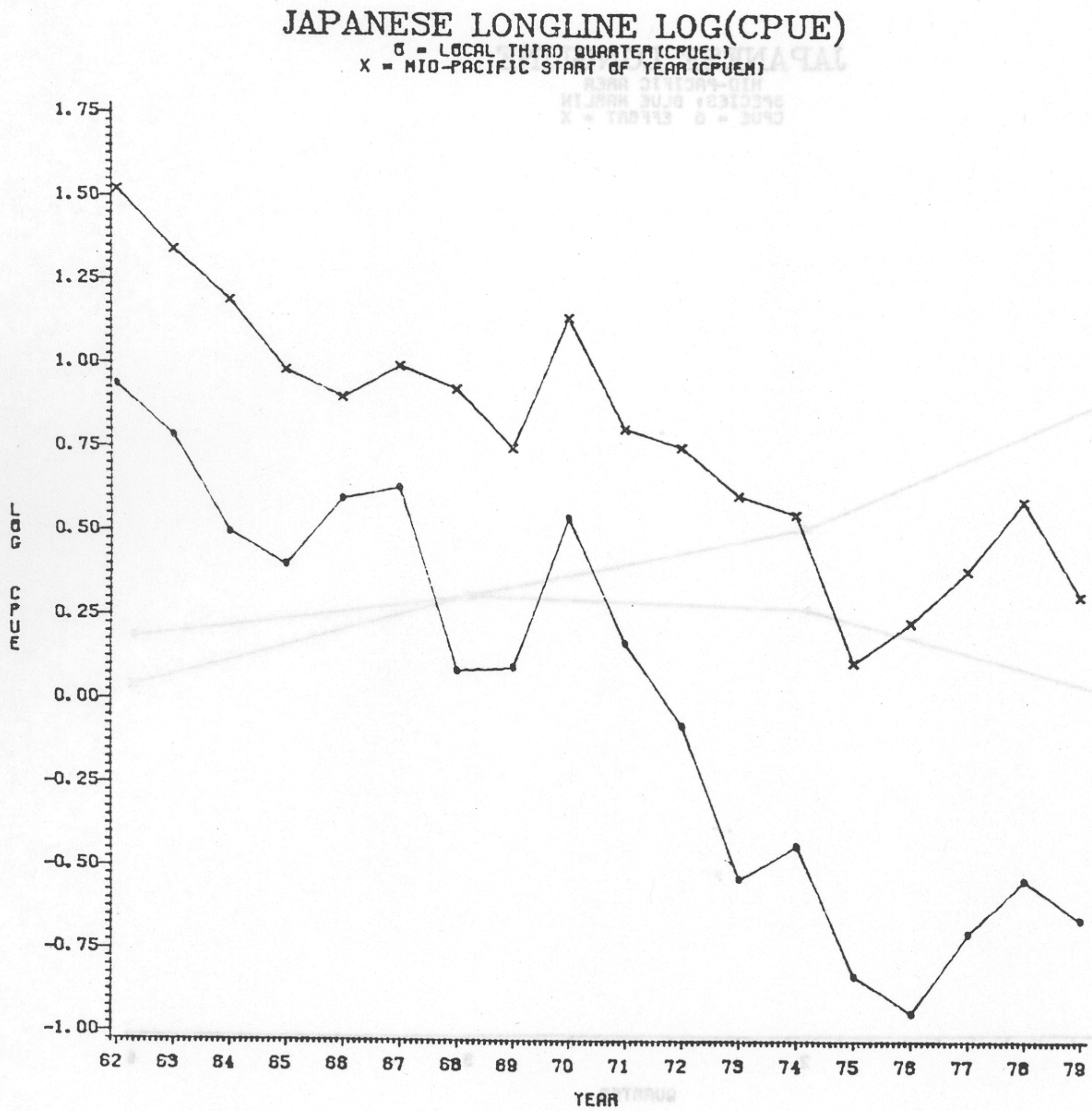

JAPANESE LONGLINE LOG(CPUE)
σ = LOCAL THIRD QUARTER (CPUEL)
X = MID-PACIFIC START OF YEAR (CPUEM)
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
LOG CPUE
62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79
YEAR

Figure 10.

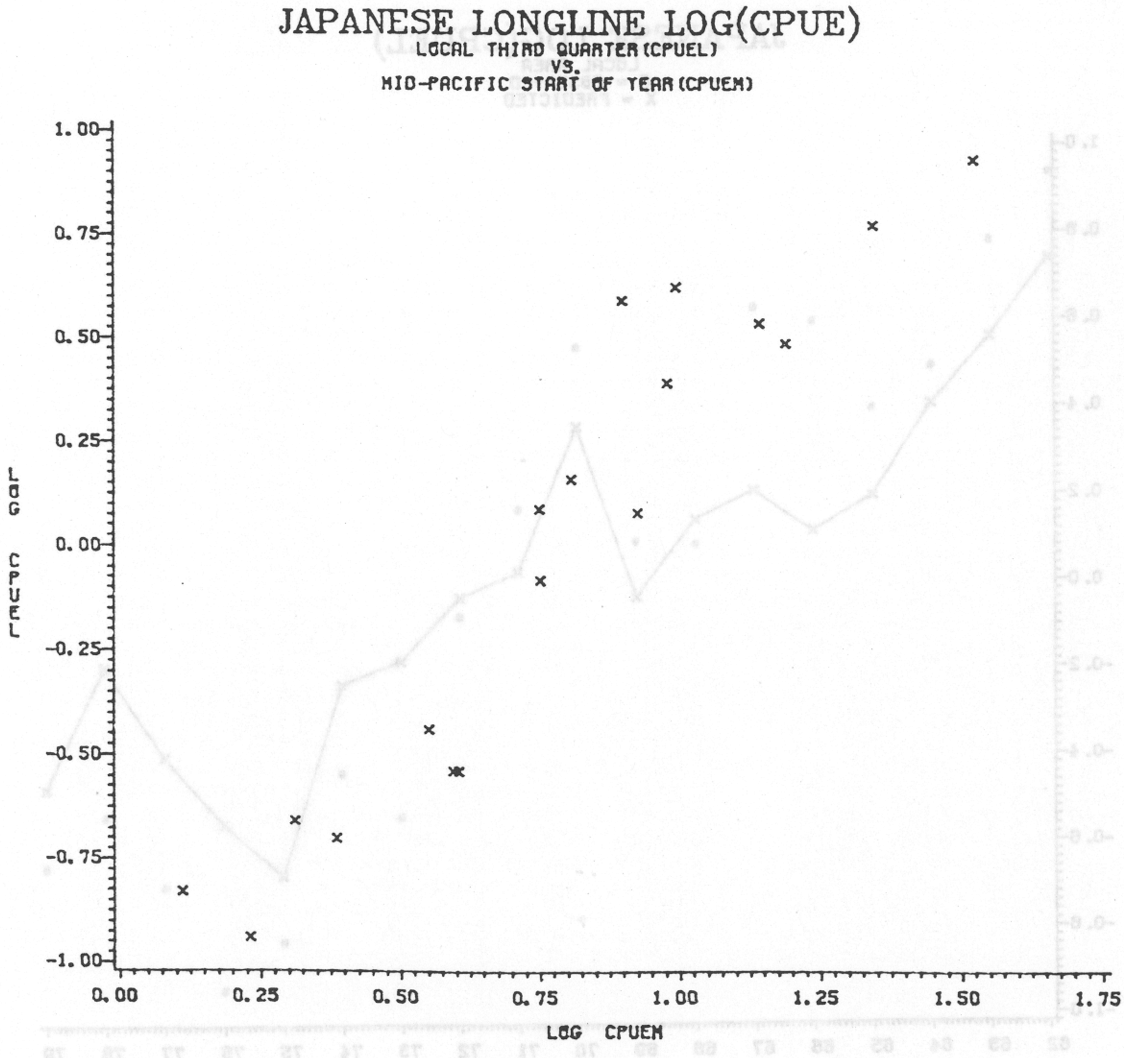

JAPANESE LONGLINE LOG(CPUE)
LOCAL THIRD QUARTER (CPUEL)
VS.
MID-PACIFIC START OF YEAR (CPUEM)
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
LOG CPUEL
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
LOG CPUEM

Figure 11.

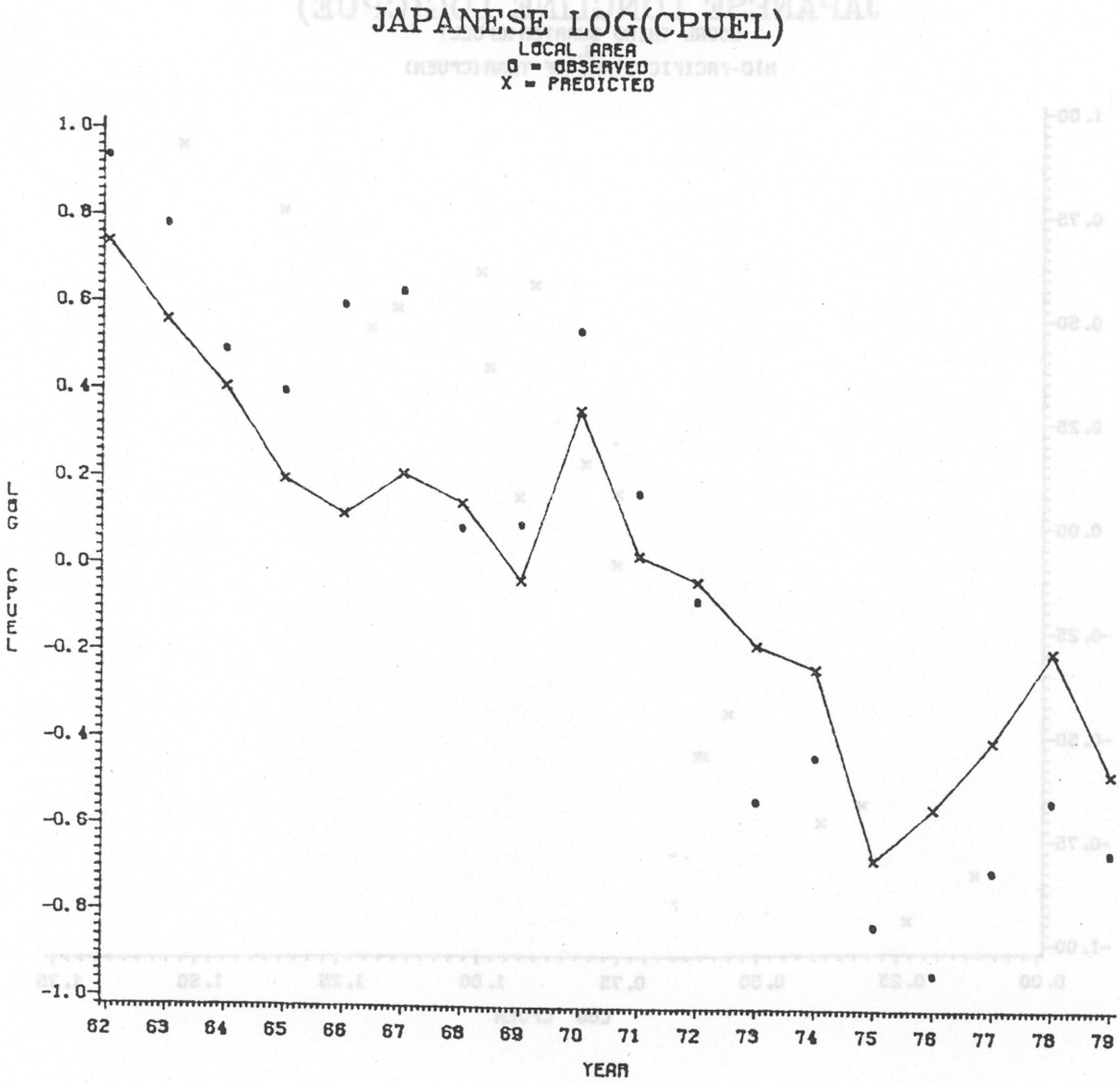

JAPANESE LOG(CPUEL)
LOCAL AREA
O = OBSERVED
X = PREDICTED
LOG CPUEL
YEAR
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79

Figure 12.

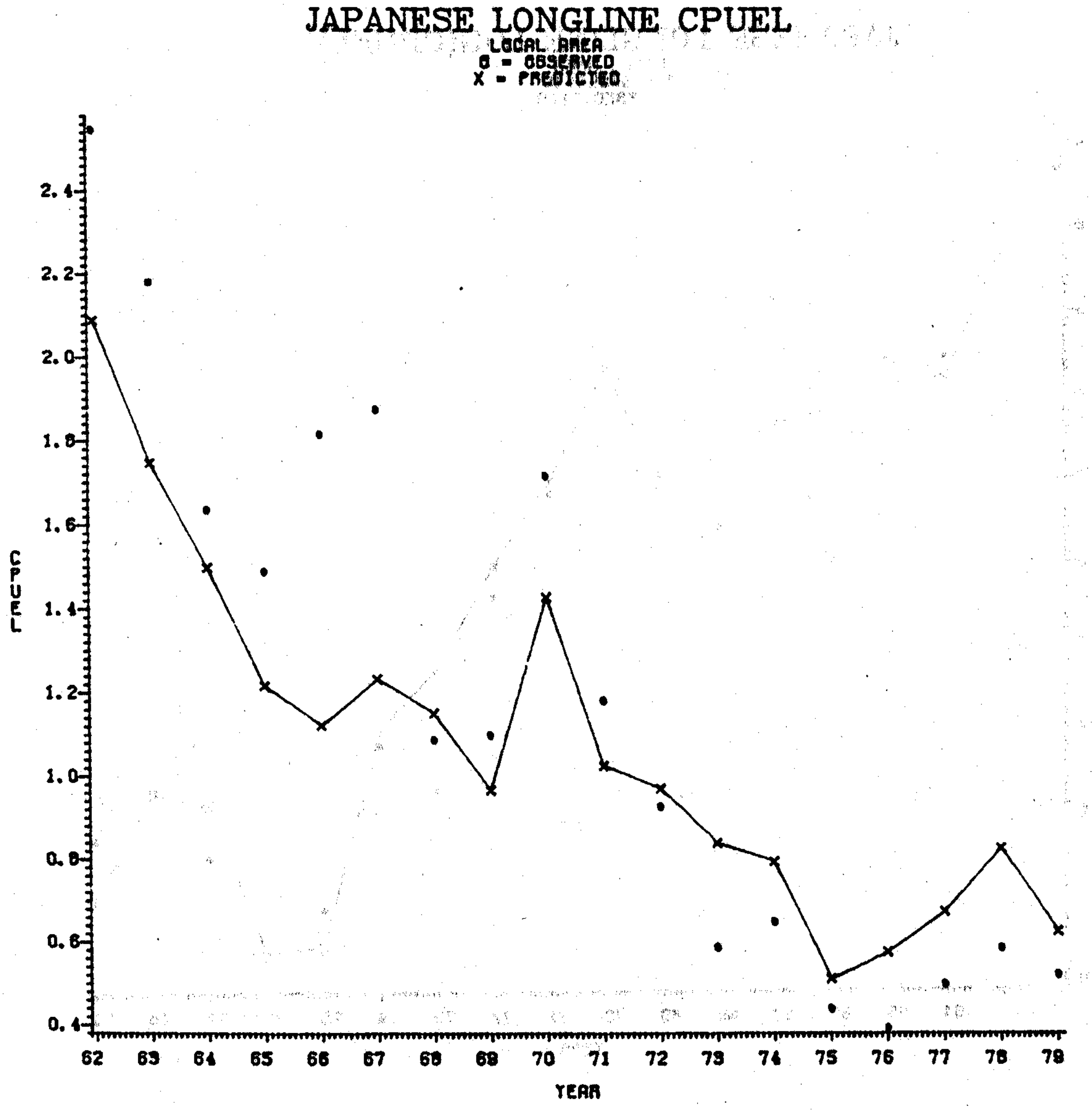

JAPANESE LONGLINE CPUEL
LOCAL AREA
O = OBSERVED
X = PREDICTED
CPUEL
YEAR
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79

Figure 13.

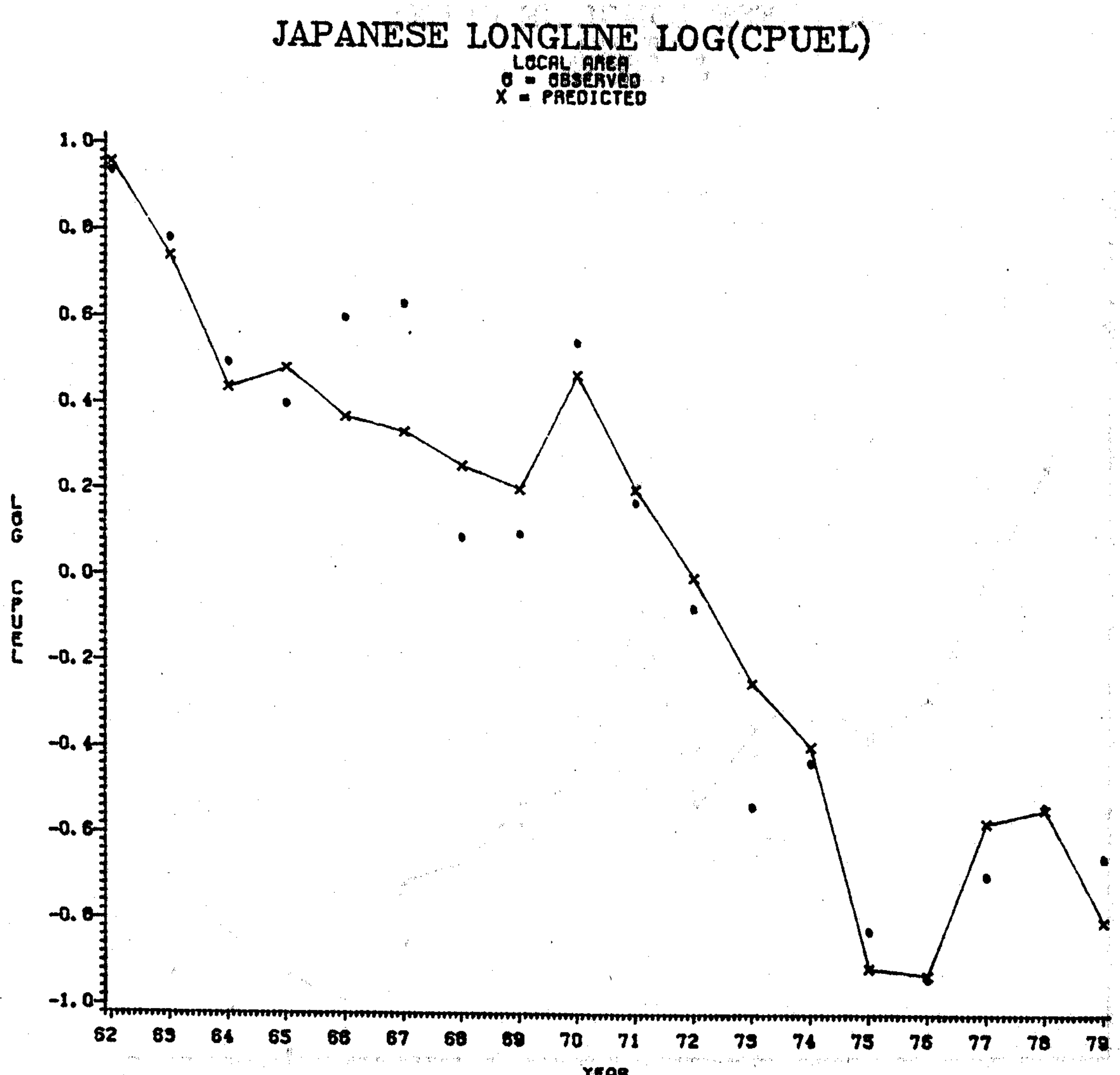

JAPANESE LONGLINE LOG(CPUEL)
LOCAL AREA
O = OBSERVED
X = PREDICTED
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
YEAR

Figure 14.

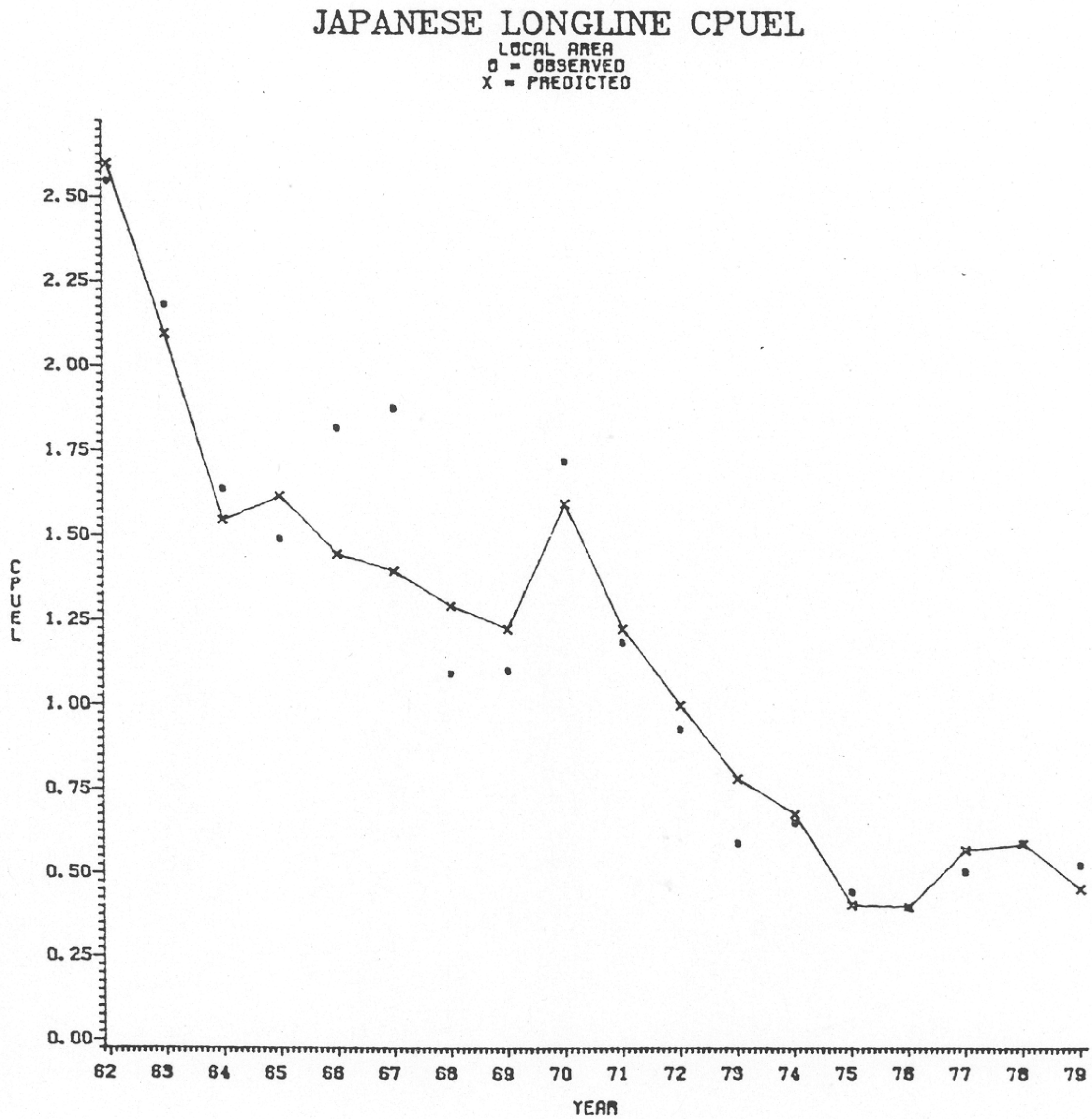

JAPANESE LONGLINE CPUEL
LOCAL AREA
O = OBSERVED
X = PREDICTED
CPUEL
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
YEAR

Figure 15.